Capacity for Rail

Towards an affordable, resilient, innovative and high-capacity European Railway System for 2030/2050

Novel Rail Freight Vehicles (Intermediate)

Submission date: 10/02/2016

Public deliverable D22.1.

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Executive Summary

WP22 is aiming to propose solutions to enhance the efficiency of Rail Freight transport. At the beginning a large forwarder operating long distance combined trains across Europe and a Car carrier operating a fleet of more than 3500 wagons involved in multimodal logistics across Europe and being also an ECM for other wagon operators have expressed their most urgent needs to increase their efficiency by reducing their operating costs while improving the quality of service. The tools that this work package wanted to develop was to increase the usable length of a standard train with new wagon designs having a lower LCC. At the same time improving the asset rotation with synchronous braking of all wagons could have reduced the wear and tear of the new composite brake blocks aiming at reducing noise.

Several designs have been studied for car carrier wagons reaching 5 bodies with 6 axels for an overall length of around 62m. For container traffics two ideas have been studied.

The first one was to introduce in a standard train composed of wagons capable to carry 40' containers or 40' plus 20' containers a partial flexibility to transport a third container type of 45' without lengthening the trains and with minimal changes on the wagons. The second idea studied was a new design of a 5 bodies wagon with 6 bogies for an overall length of around 72m. This solution was aiming to reduce the number of bogies and hence the maintenance cost. A third idea was to develop the same concept for transport of crane-able semitrailers with a 4 bodies wagon with 6 bogies for an overall length of around 67M.

Each of these solutions were studied successfully in term of stability with the mathematical programs of KTH. The cost of these new designs were estimated by NTnetAB and the operational efficiencies calculated when possible or estimated according to expert experience. The impact in terms of temperature reduction with synchronous braking showed a significant decrease on the test benches of Knorr Bremse. Unfortunately new braking methodologies by applying successively strong braking followed by a release have reduced the temperature reached by the blocks and the wheel treads in a zone where the impact of the synchronous braking would not bring significant maintenance cost reduction and damage reduction.

For the new wagon designs the cost benefit analysis show interesting progress for the car carrier wagon and the container wagon but not for the pocket wagons. The flexibility of putting a third of the number of container with a length of 45' without lengthening the train may be very promising. Finally an extremely promising field is to significantly reduce the preparation time before the departure of the train with the introduction of an EOT (End of Train) device. This intermediate deliverable will be completed in the next issue with the introduction of these new designs on the Network and with a possible roadmap to mobilize investors to create these new wagons.

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1 Background and Objectives of WP2.2: Novel rail freight vehicles

1.1 Fixing the functional targets

The first step of the work in this deliverable was to analyze the customers' demands which were to be satisfied two main customers were involved in that work:

- A large intermodal forwarders (Van Dieren) using full trains crossing Europe from Sweden to Italy via Duisburg in Germany
- A major automotive multimodal logistics operator (STVA) owning 4500 rail cars for finished vehicles, operating fleet of trucks carrying vehicles , managing terminals for car storage and cars adaptation to national standards and being ECM(entity in charge of maintenance) for several large fleets of wagons of different types.

For both of them the main needs were reliability and cost reduction.
At the same time the rail community is facing new stringent rules in the field of noise reduction having a significant impact on the cost of daily wagon utilization.

Basically the main conclusions of this first analysis were simple:

- Find new designs to reduce the dead weight, to increase the usable length of the wagons within the overall length accepted by the Infrastructure managers and without reducing the safety at acceptable speed limits.
- Find solutions that will give more flexibility to the wagons to carry different types of loads specifically in the field of intermodal wagons.
- Find solutions that could reduce the costs created by the new solutions reducing rail noise and which could globally reduce the maintenance costs.
- Find solutions to improve the train maneuverability in terms of braking and releasing the brakes.

In the limited scope of the C4R project linked to the volume of resources attributed to this work package the objective was to imagine the solution, to check its technical feasibility, to assess its impact on the parameters characterizing an improvement on the items listed here above, to assess its safety or to define the operational constraints to be respected in order to maintain the safety level, to estimate the cost of the solution (on the basis of an industrial production) and finally to perform a limited cost benefit analysis in this first part of WP22.

In a second part of the work which will be in the final deliverable, the cost benefit analysis will have to be extended to the train in its environment taking into account its insertion in the traffic, a road map for its introduction in the market, the consequences on the other traffics if any, the impact on the other logistics operations and a possible way to share the benefits among the actors to ensure an alignment of the interests to develop and introduce such solutions.

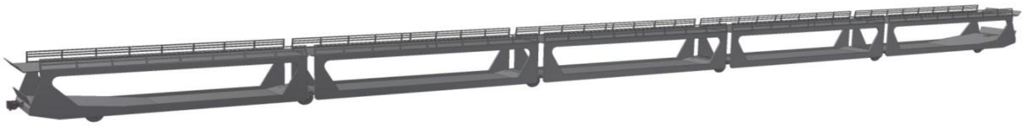
1.2 From the functional targets to the technological proposals

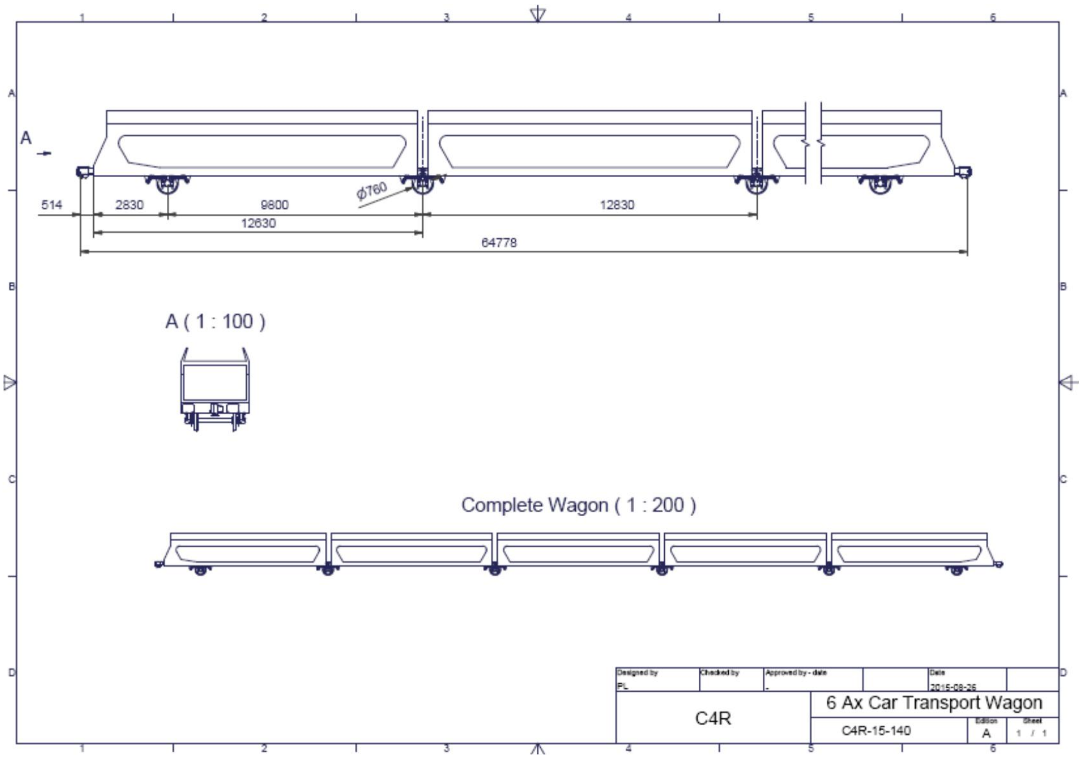
a. Gaining usable length in a given maximum train length

In a train the non-usable length is constituted by the buffers between the wagons. This is necessary if you frequently need to decouple the wagons during your operations. The obvious solution partially applied on certain trains is to introduce draw bars between the wagons. The inconvenience is to have a risk of losing huge time if you have a technical problem on one wagon in a set of multiple wagons. You may be obliged to withdraw a full set of wagon linked by draw bars to ensure rapidly the continuity of the service. So either you have a spare set available or you must change your maintenance methodology to switch to predictive maintenance which is a point which will be dealt further.

The solution has been studied for two different cases: light automotive transport and heavy intermodal transport.

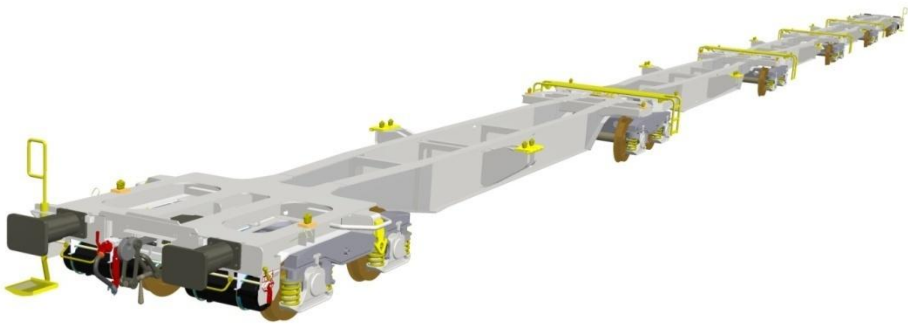
- In the first case a 6 axel car design for transport of finished vehicles has been drawn according to the scheme under:



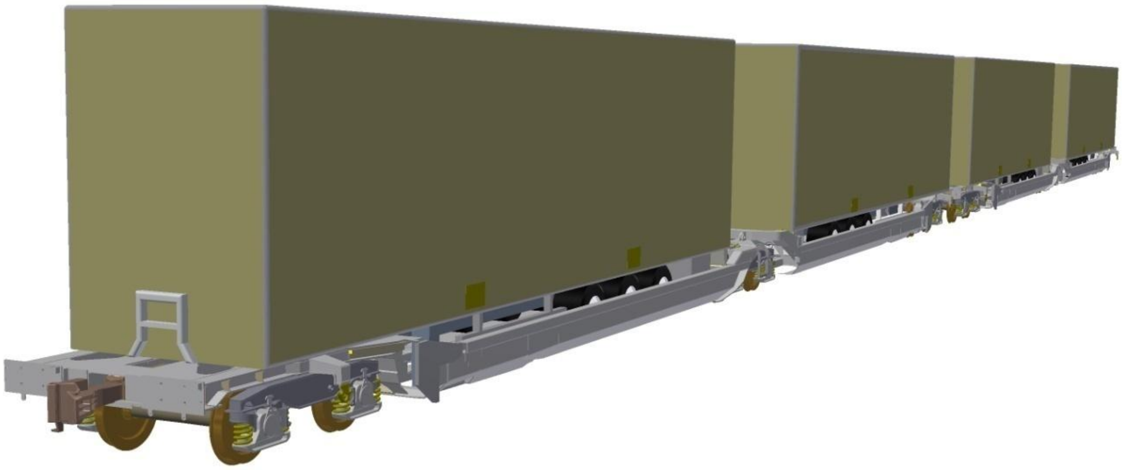


This design elaborated by Ntnet AB with certain variables has been studied by KTH Royal institute of Technology to check its stability within certain speed limits. Of course this solution is only compatible with light cargo.

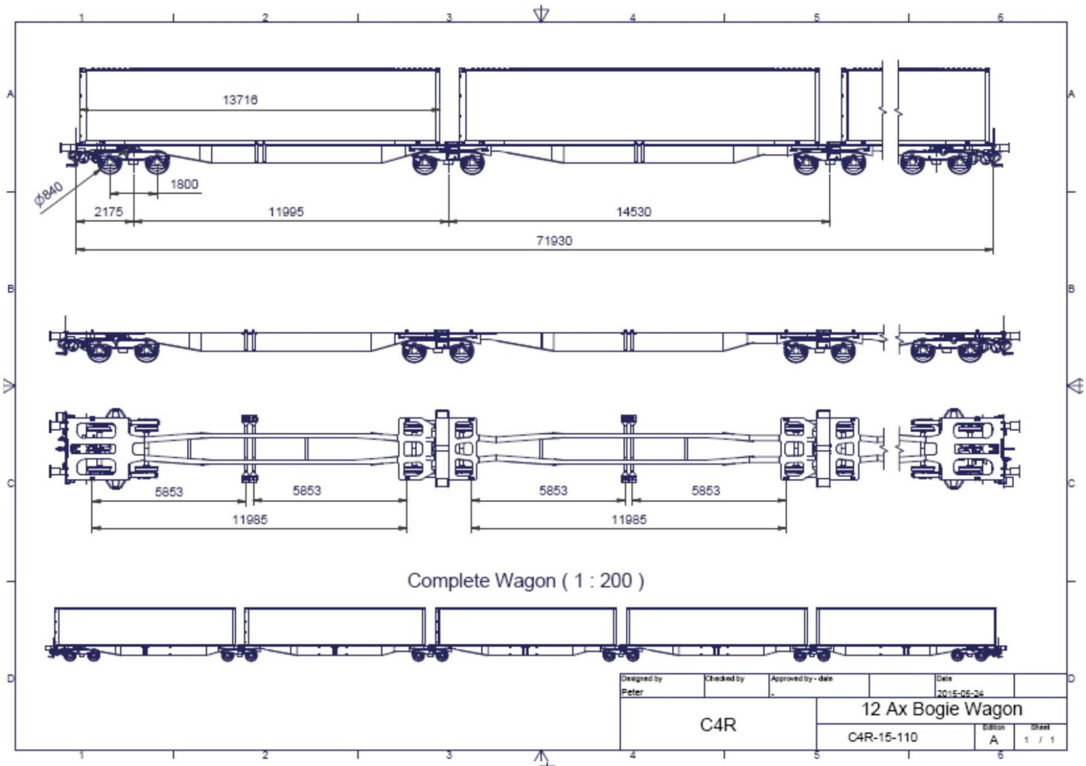
- A second solution has been designed for intermodal transport where the weight of the cargo is significantly higher. It is a 12 axel-car design.



To keep the carrying capacity despite the reduction of the number of axels a new structure has been completely designed to reduce the weight of the structure.



The first drawing is for containers or swap bodies and the second drawing is for semitrailers.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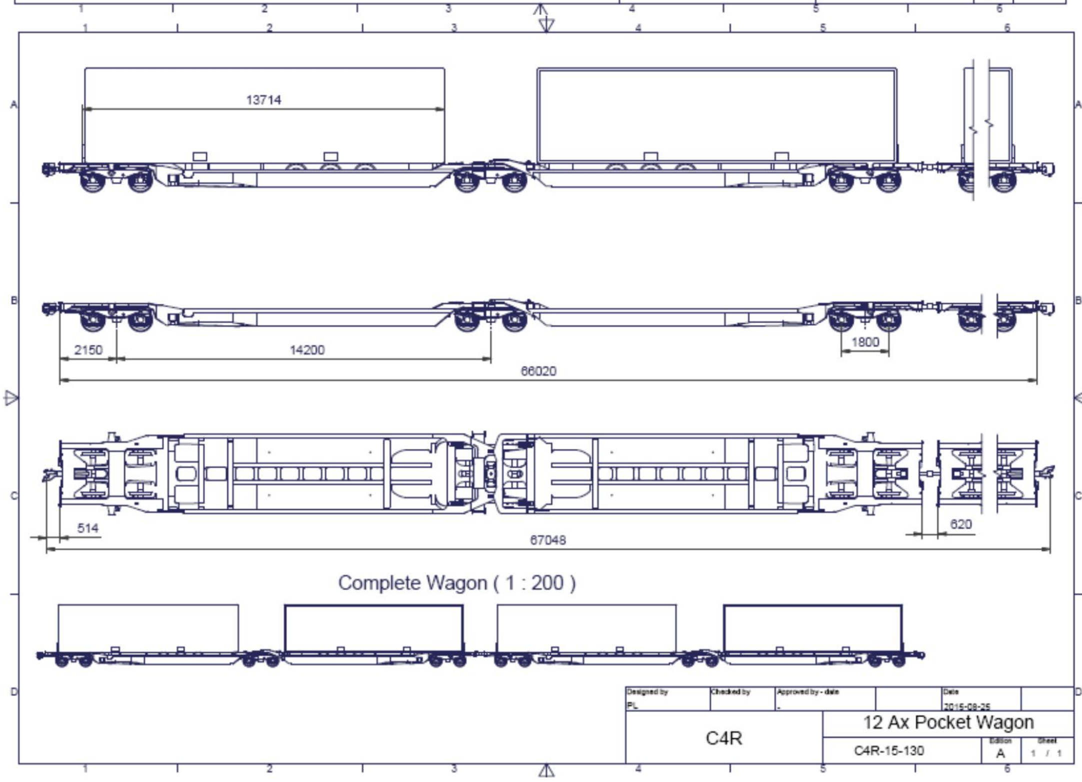
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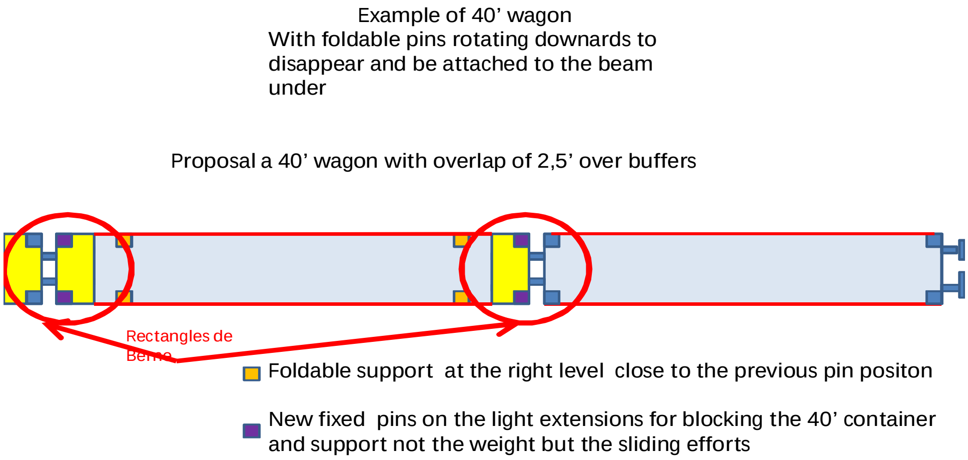
b. <u>Gaining flexibility in transport of different intermodal units.</u>

Huge traffics are arriving in ports from overseas countries. They are then distributed by trains to far destinations. For productivity reasons 45' containers are becoming more frequent in such traffics. Repositioning of containers are not in general done by the port of entrance and it is frequently necessary to have the capacity of transporting some 45'containers on trains full of 20' and or 40' containers. The possible solution is to have systematically 45' instead of 40' capacity on each wagon. The immediate consequence is that every 8 th wagon you have lost a 40' container carrying capacity which is a serious penalization of 12.5% on a train of 720m of wagons with an allocation of 30m for the locomotive.

The idea proposed is to extend on both ends of the wagon the platform over the buffers by 2.5'. This of course does not leave the Bern rectangle which is necessary for the safety of the staff when decoupling wagons during the operation. The proposed solution is to create non de-couplable triple wagons where the middle one will be extended over buffers by 2.5' at each end. This gives a capacity of 17 containers of 45' on 51 wagons for 40' containers without extending the overall train length. The inconvenience is the risk of taking out 3 wagons if there is a technical problem which suggest to switch also to predictive maintenance.

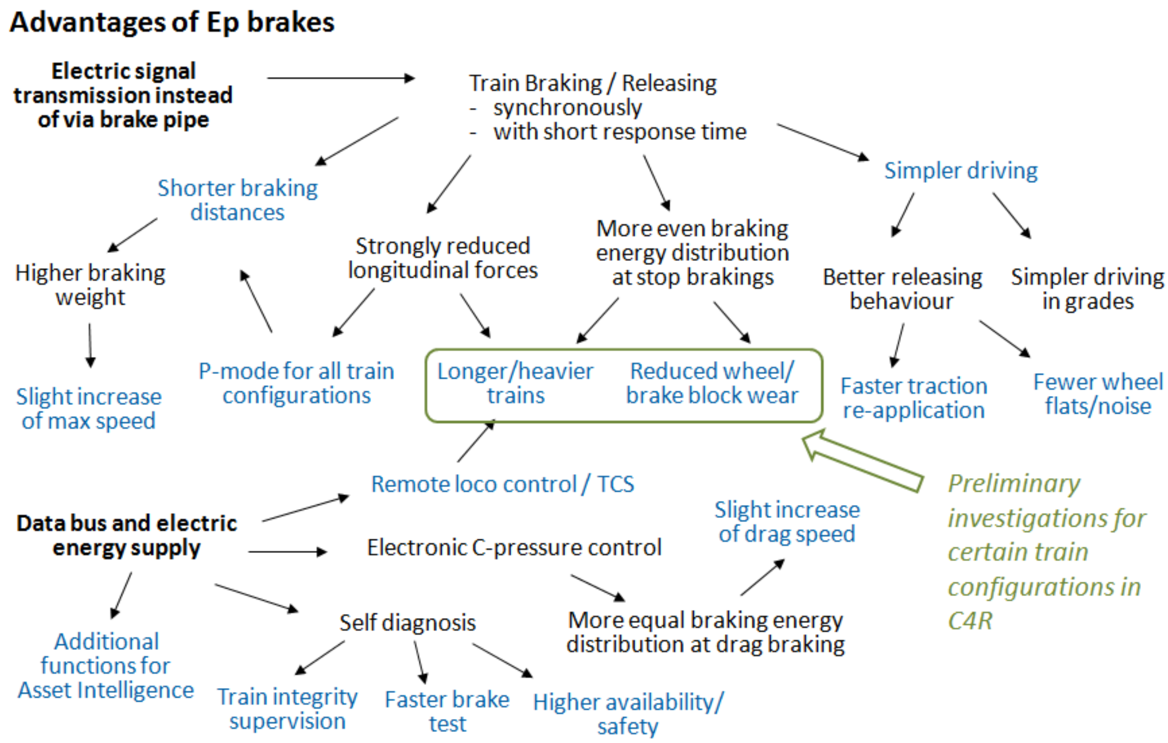


c. <u>Costs reduction in maintenance of new brake shoes aiming to reduce noise and more generally in maintenance.</u>

Reduction of rail noise is necessary for an improved acceptability of rail freight transport. Two types of noise are generated: the general rolling noise and the noise generated when the train is braking. The second noise is the most aggressive one and lots of studies have been aiming at finding a type of shoe having a significant noise reduction effect. Two types of brake blocks have been experimented K-blocks and LL-Blocks.

K-Blocks are much more costly than cast iron blocks and need a modification of wagons which braking system is not equipped with auto-variable. More over certain types of K-Blocks are very aggressive with the wheels which have to be reworked more frequently.

LL-blocks have the advantage not to need the installation of the costly auto-variable system but they are much more costly that the cast iron blocks and are also very aggressive with the wheel implying a more frequent reworking.
The research path adopted in C4R was to try to reduce the braking effort between the shoe and the wheel to try to reduce the wear and tear created by these new blocks. The idea being that if the effort is reduced, the temperature at the contact point should decrease and the aggressiveness should be reduced.
To achieve a reduced braking effort the idea has been to have a simultaneous braking of all wagons, by an electric opening of a braking valve on each wagon. This would be an overlay on the actual braking system which will remain as a back up to guarantee the safety. The installation of an electric line all along the train would allow many other improvements and in particular the capacity to introduce the predictive maintenance among others as shown in the attached document elaborated by Knorr Bremse:

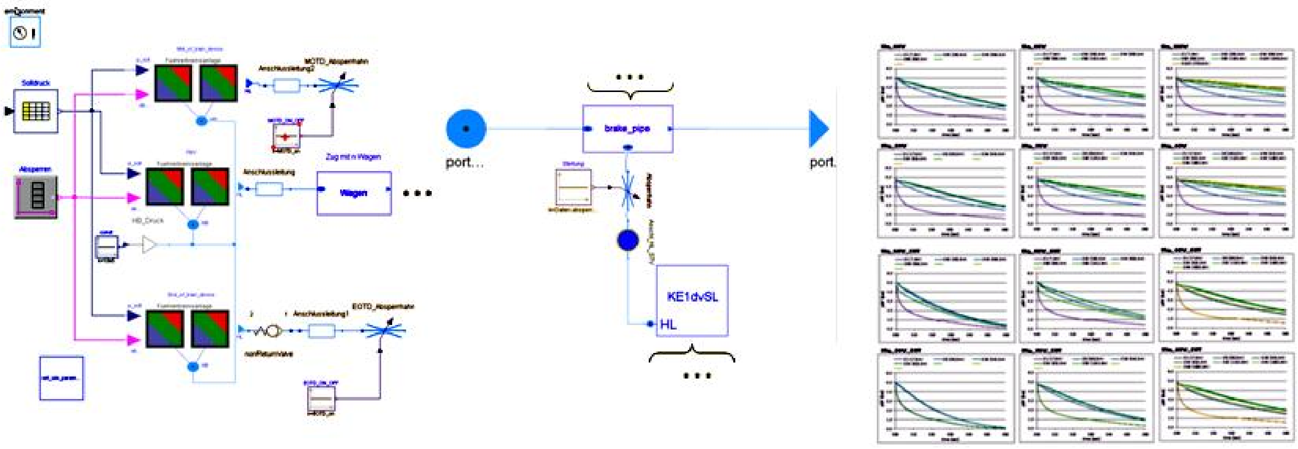


Knorr Bremse was in charge to analyze the impact of synchronous braking on the shoes temperature at the surface of contact with the wheel. At the same time KB performed an analysis to detect which element of this virtuous circle generated by the continuous electric line and the bus of information it was able to carry would have the highest impact on the operation efficiency.
KB was also in charge of modeling the braking of the new designed multi axel wagons in order to allow KTH to perform the analysis of the longitudinal efforts and give a preliminary opinion on the safety of these new designed wagons incorporated in different type of trains.

The results of KB work are described in the following tables:

Brake system design and simulation

1. Modelling of base variants
2. Sensitivity analyses
3. Base simulations of brake pipe behaviour for different train lengths, wagon lengths, brake types (conv. pneumatic UIC brake, EOT, MOT, EP) and scenarios (Full Service brake, Releasing, Emergency Brake)



Brake system design and simulation, cont'd

4. Individual brake system layouts and parameters for conventional and novel freight wagons
5. Individual brake simulations based on interpolations between relevant base simulations and wagon-specific post-processing to generate the relevant pressure and force data for the respective brake equipment, loading state, brake mode etc.
6. Documentation of main results

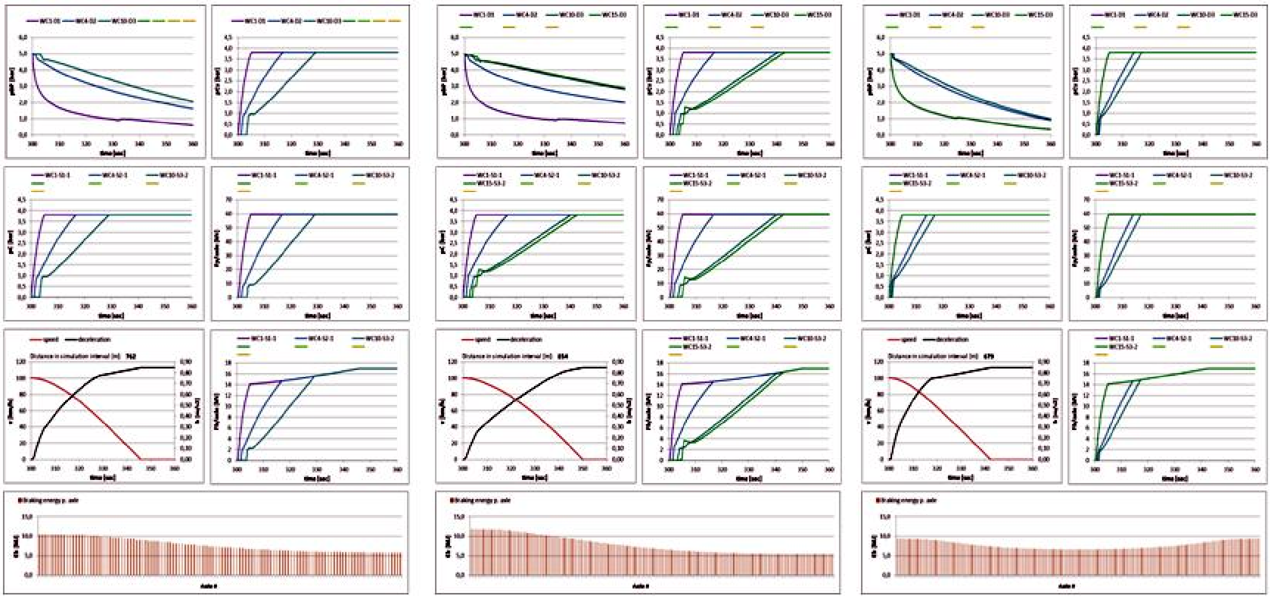
The analysis performed are similar to what is displayed in the next table:

Exemplary Simulation Results – articulated 12 axle container wagon consist

1100m, conv, pneumatic

750m, conv. pneumatic brake

1100m, conv. pneumatic brake

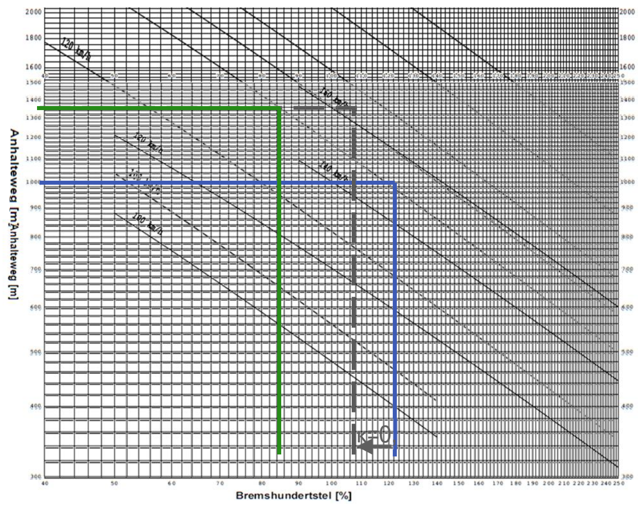


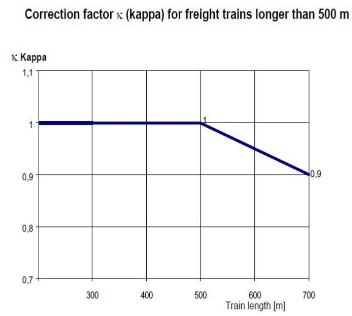
As regards the Braking performance to ensure a correct and safe stopping distance:

Braking performance of Ep brakes

- Given a 750m train of λ_{train} = 90% (all λ_{wagon} = 100%), Ep brake allows a reduction of train braking distance from ≤ 900m to 700m (blue line in diagram)
- Alternatively, given that its effect is fully rated in the braking weight, it allows to achieve 900m braking distance for wagons with 100/74 = 135% of their conventionally allowed axle load (green line in diagram)

Braking distance [m]

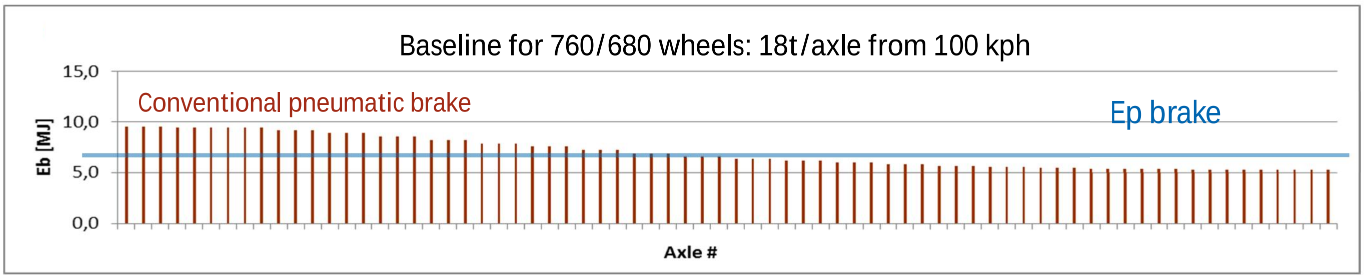


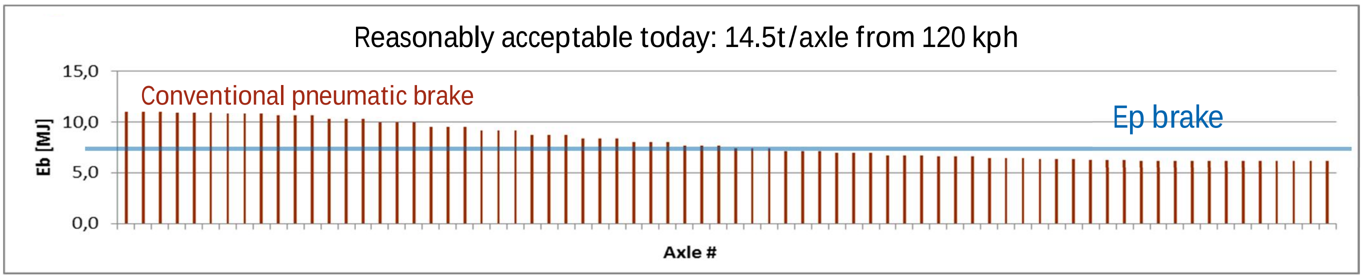


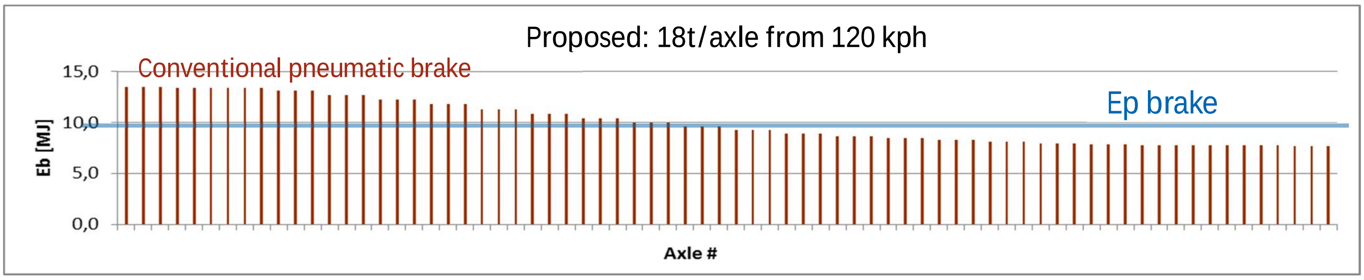
Braking percentage [%]

To appreciate the impact of certain braking's on the temperature of the contact surface the methodology was to appreciate the energy involved in the operation and its distribution on the different axels of the train; an example of the simulation results is given here under:

Braking Energies – Emergency braking's with novel STVA car transport train of 750m







The complete set of results of the simulations performed by KB are in a separate document which has been used by KTH to perform the analysis of longitudinal efforts and to assess the safety of the solutions.

2 Dynamic analysis for the various solutions to assess the stability and analysis of shoes and wheels wear and tear evolution by KTH

This part is to check the stability of the different new designs in the various conditions of operations. It is also to validate if there is a positive impact of various braking solutions on the shoes wear and tear and on the wheel wear and tear.

2.1 Dynamic analysis of novel vehicle concepts for improved network capacity

This chapter intends to verify the feasibility of the proposed vehicles from the dynamic point of view. The main innovations that have impact in the dynamics of the system are:

- Vehicle type and characteristics
- Brake type

2.1.1 Vehicle characteristics

From the wagon types under investigation in C4R, there are two types of vehicles whose dynamic analysis has been performed.

- Bogie wagons:
  - Conventional 4-axle container wagons (type Sgg…), 840/760 wheels, 20t/axle
  - Conventional articulated 6-axle container wagons (type Sgg…), 840/760 wheels, 20t/axle
  - Novel articulated 12-axle container wagon consists, 840/760 wheels, 20t/axle
- Single wheel set wagons
  - Conventional 2-axle short-coupled car transport wagons (type Laes), 760/680 wheels, 18t/axle
  - Conventional 3-axle car transport wagons (type Laes), 760/680 wheels, 18t/axle
  - Novel 6-axle car transport wagon consists (STVA concept), 760/680 wheels, 18t/axle

Modelling of these wagons has been performed according to the technical data provided by STVA and NTnet AB. The selected MBS software is Gensys[1]. When building the multibody simulation models, the local coordinate systems of the shared bogies and/or wheel sets has been referenced to the preceding car body.

The feasibility of these novel vehicles has been assessed by studying the dynamics of the different vehicles is split in two different cases: lateral dynamics (critical speed and curving behavior) and longitudinal dynamics (force transfer on buffers while braking).

2.1.2 Dynamic analysis: lateral dynamics

Simulation cases: critical speed

The simulation cases for the critical speed of the shared bogie vehicles have been summarized in table 1

Table 1 – summary of simulation cases for critical speed calculations of articulated bogie vehicles.

	1 car	2 car	5 car
18 tons	340mm	340mm	340mm
	380mm	380mm	380mm
20 tons	380mm	380mm	380mm
	420mm	420mm	420mm
22.5 tons	420mm	420mm	420mm
	460mm	460mm	460mm
Empty car(s)	340mm	340mm	340mm
	380mm	380mm	380mm

	420mm	420mm	420mm
	460mm	460mm	460mm
Adjusted load 18 tons	340mm		
	380mm		
Adjusted load 20 tons	380mm		
	420mm		
Adjusted load 22.5 tons	420mm		
	460mm		

In the given case table:

- The green column correspond to different axle load
- The red row correspond to varying number of cars
- The purple columns represent the different wheel radius for a particular load case and the number of cars.

Hence, in total there are 30 cases to be simulated.

In addition to the above 30 cases, there are an additional 6 cases, for single car bogie vehicle with axle load equal to the axle load at the end bogies of a 5 car articulated vehicle (reduced load). These cases were performed in order to see the influence of the lower load in the first bogie for the articulated vehicles.

Hence the total number of cases: 36.

Similarly, the simulation cases for the critical speed of the shared wheel set vehicles have been summarized in table 2

Table 2 – summary of simulation cases for critical speed calculations of articulated single wheel set vehicles.

	1 car	2 car	5 car
18 tons	380mm	380mm	380mm
20 tons	420mm	420mm	420mm
22.5 tons	460mm	460mm	460mm
Empty car(s)	380mm	380mm	380mm

In the empty case, the cars with the minimum wheel radius are only simulated since for larger radius, the critical speed will be higher.

The total number of simulation cases for the shared wheel set system is 12.

Simulation cases: curving behavior

The simulation cases for examining the curving behavior of the vehicle were decided on the basis of UIC 518 on testing and approval of railway vehicles from the point of view of their dynamic behavior- safety-track fatigue-running behavior.

Based on the guidelines, the vehicle is to be a tested for curve radius= 250m (small radius curve) and 500m (medium radius curve). The vehicle is to be tested at constant speeds corresponding to:

1. The equilibrium speed with a cant of 130mm.
2. Cant deficiency of 25% for the same speed in the first case.
3. Cant excess of 10% for the same speed in the first case.

The list of the cases have been summarized in the table below with corresponding wheel radius(mm), load(tons),number of cars and the corresponding cant(mm):

Table 3 – summary of simulation cases for curving behavior calculations of articulated bogie vehicles.

Case	5car	1car
bogie-340-18t	cant 130	cant 130
	cant 143	cant 143
	cant 97,5	cant 97,5
bogie-380-18t	cant 130	cant 130
	cant 143	cant 143
	cant 97,5	cant 97,5
bogie-380-20t	cant 130	cant 130
	cant 143	cant 143
	cant 97,5	cant 97,5
bogie-420-20t	cant 130	cant 130
	cant 143	cant 143
	cant 97,5	cant 97,5
bogie-420-22,5t	cant 130	cant 130
	cant 143	cant 143
	cant 97,5	cant 97,5
bogie-460-22,5t	cant 130	cant 130
	cant 143	cant 143
	cant 97,5	cant 97,5
bogie-340-empty	cant 130	cant 130
	cant 143	cant 143
	cant 97,5	cant 97,5
bogie-380-empty	cant 130	cant 130

	cant 143	cant 143
	cant 97,5	cant 97,5
bogie-420-empty	cant 130	cant 130
	cant 143	cant 143
	cant 97,5	cant 97,5
bogie-460-empty	cant 130	cant 130
	cant 143	cant 143
	cant 97,5	cant 97,5

The total number of cases to be simulated for determining curving behavior in case of the shared-bogie system is 60.

Similarly, for the shared-wheel set system:

Table 4 – summary of simulation cases for curving behavior calculations of articulated single wheel set vehicles.

Case	5car	1car
wheelset-380-18t	cant 130	cant 130
	cant 143	cant 143
	cant 97,5	cant 97,5
wheelset-420-20t	cant 130	cant 130
	cant 143	cant 143
	cant 97,5	cant 97,5
wheelset-460-22,5t	cant 130	cant 130
	cant 143	cant 143
	cant 97,5	cant 97,5
wheelset-380-empty	cant 130	cant 130
	cant 143	cant 143
	cant 97,5	cant 97,5
wheelset-420-empty	cant 130	cant 130
	cant 143	cant 143
	cant 97,5	cant 97,5
wheelset-460-empty	cant 130	cant 130
	cant 143	cant 143
	cant 97,5	cant 97,5

The total number of cases to be simulated for determining curving behavior in case of the shared-bogie system is 24.
The cases described above correspond to simulations performed for a single value of curve radius.

Design of Boundary conditions:

The boundary conditions for:

Critical Speed Simulation	The vehicle is initially given a high speed with a small value of retardation over the time interval of the simulation. Thus, the vehicle is initially unstable and reduces its critical speed until it becomes stable. The lateral displacements of the wheel sets are plotted as a function of speed to find the critical speed.
Curving Behavior	The vehicle is given the equilibrium speed for at a cant of 130mm in all the cases and the Y/Q ratio examined to determine the curving behavior. The UIC standards are followed, which require Y/Q to be lower than 0.8.

It is to be noted that in case of the simulations involving shared wheel sets, the non-linear friction elements prevent the simulation from starting because of mathematical errors while executing. To solve this, special simulations have been run with a slightly modified suspension to create a stable running vehicle. Later, these conditions and position of the vehicle are replicated as the initial running condition with the original vehicle, allowing the correct simulations to be performed.

Results and Discussions:

1.1. Critical speed: The critical speed in (km/h) corresponding to the different cases, all of them with a friction value of 0.35 at the wheel rail contact, are described below:

1.1.1. 5 car shared bogie model:

Table 5 – Critical speed value for 12 axle articulated vehicle, laden

	680.00	760.00	840.00	920.00	Wheel Diameter (mm)
18.00	83.00	87.00	X	X	
20.00	X	92.00	96.00	X	
22.50	X	X	102.00	106.00	
Axle load(tons)					

Table 6 - Critical speed value for 12 axle articulated vehicle, empty

Wheel Diameter (mm):	Critical speed (km/h)
680.00	64.00
760.00	67.00
840.00	69.00
920.00	71.00

1.1.2. 2 car shared bogie model:

Table 7 - Critical speed value for 6 axle articulated vehicle, laden

	680.00	760.00	840.00	920.00	**Wheel Diameter (mm):**
18.00	**81.00**	**85.00**	X	X	
20.00	X	**90.00**	**94.00**	X	
22.50	X	X	**101.00**	**104.00**	
Axle load(tons)					

Table 8 - Critical speed value for 6 axle articulated vehicle, empty

Wheel Diameter (mm):	Critical speed
680.00	64.00
760.00	67.00
840.00	68.00
920.00	72.00

1.1.3. Single car with 2 bogies:

Table 9 - Critical speed value for 4 axle single car vehicle, laden

	680.00	**760.00**	**840.00**	**920.00**	**Wheel Diameter (mm):**
18.00	**95.00**	**100.00**	**X**	**X**	
20.00	**X**	**109.00**	**113.00**	**X**	
22.50	**X**	**X**	**121.00**	**123.00**	

Axle load(tons)

Table 10 - Critical speed value for 4 axle single car vehicle, empty

Wheel Diameter (mm):	Critical speed
680.00	61.00
760.00	63.00
840.00	66.00
920.00	68.00

1.1.4. Single car with 2 bogies (with adjusted load):

Table 11 - Table 12 - Critical speed value for 4 axle single car vehicle with reduced vertical load, laden

	680.00	760.00	840.00	920.00	Wheel Diameter (mm):
18.00 ton equivalent	78.00	81.00	X	X	
20.00 ton equivalent	X	86.00	89.00	X	
22.50 ton equivalent	X	X	98.00	101.00	
Axle load(tons)					

1.1.5. 5 car shared wheel set model (loaded):

Table 13 - Critical speed value for 6 axle articulated car transport vehicle, laden

	760.00	840.00	920.00	Wheel Diameter (mm):
18.00	148.00	X	X	
20.00	X	210.00	X	
22.50	X	X	197.00	
Axle load(tons)				

1.1.6. 2 car shared wheel set model (loaded):

Table 14 - Critical speed value for 3 axle articulated car transport vehicle, laden

	760.00	840.00	920.00	Wheel Diameter (mm):
18.00	190.00	X	X	
20.00	X	226.00	X	
22.50	X	X	252.00	
Axle load(tons)				

1.1.7. Single car with 2 wheel sets (loaded):

Table 15 - Critical speed value for 2 axle short-coupled car transport vehicle, laden

	760.00	840.00	920.00	Wheel Diameter (mm):
18.00	330.00	X	X	
20.00	X	440.00	X	
22.50	X	X	485.00	
Axle load(tons)				

1.1.8. Empty wagons with wheel diameter 760mm

Table 16 - Critical speed value for the different car transport vehicle configurations, empty

Case	Critical speed (km/h)
5 car shared wheel set system (empty)	111.00
2 car shared wheel set system (empty)	165.00

1 car shared wheel set system (empty)	**110.00**

Conclusions: bogie vehicles

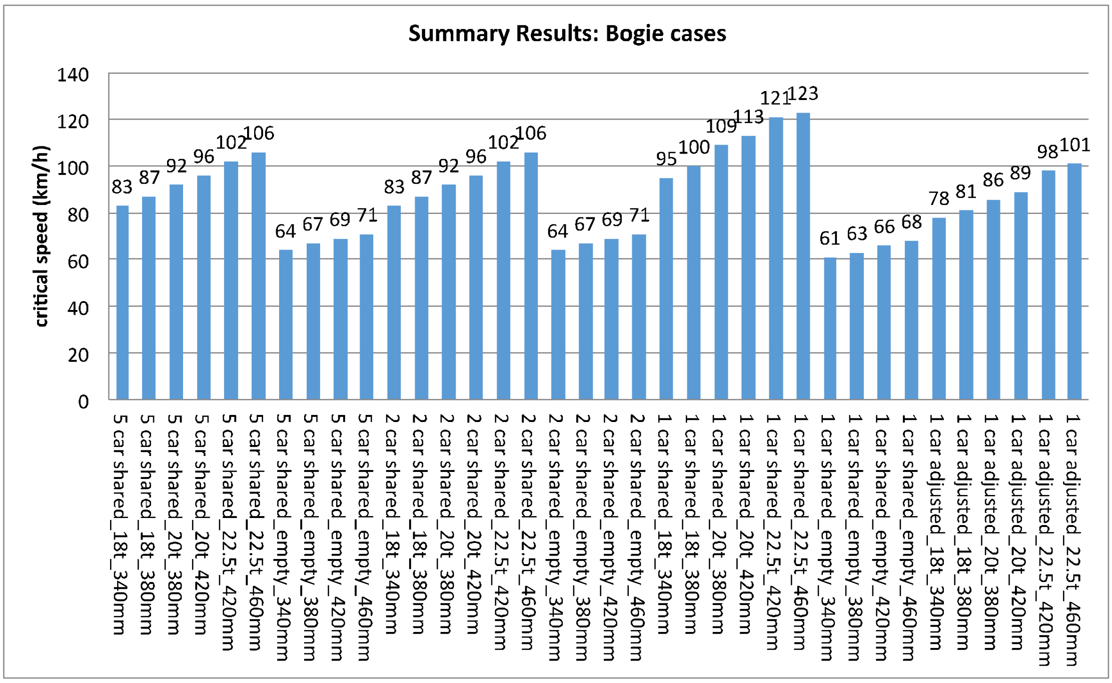


Figure 1 – Summary of the critical speed of the shared bogie cases.

The theoretically calculated critical speeds for bogie vehicles are relatively low compared with the speeds these vehicles are designed to run in real life, i.e. 100km/h laden and 120km/h empty. This has been investigated but no satisfactory answer has been found. In fact, theoretical studies of empty Y25 wagons in the literature [2], [3]deal with critical speeds between 60km/h and 80km/h, similar to the ones obtained in this study. It should be mentioned that the friction value in the contact patch is 0.35. If this value is reduced to 0.15, the critical speed increases substantially, up to more than 100km/h. The study is still kept with the original friction value because the relative comparison between the reference vehicle and the novel vehicle is still valid.

For a better understanding of the figure, a reduced case set is depicted in the next figure. The critical speed for the 1 car vehicle is used as reference, a regular container transport with Y25 bogies. When using an articulated configuration, critical speed is reduced ca. 17%, but it is not important the number of wagons coupled in the configuration. This is because the ultimate cause for the reduction of critical speed is not about the number of vehicles, but about the axle load. In the articulated vehicles, first and last bogies have a reduced axle load compared to the intermediate wheel sets, so the critical speed is slightly reduced. In order to study the effect of load reduction on the single non-articulated vehicle, another case has been simulated with a single vehicle with a load equivalent to the first wheel sets in the articulated configurations. In this case the speed is reduced even below the articulated configurations.

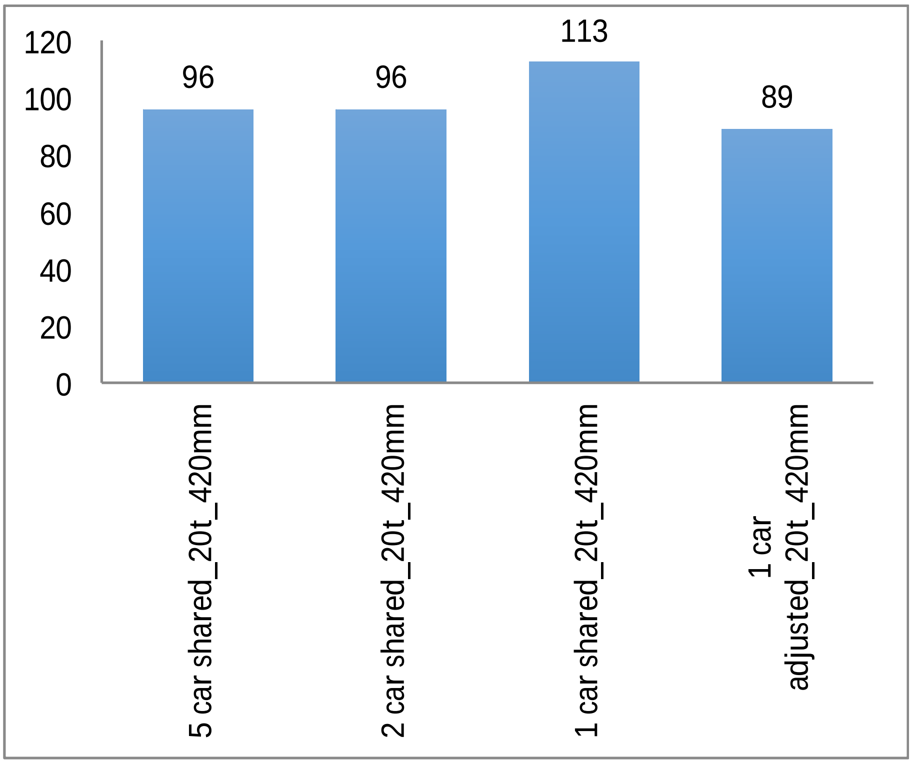


Figure 2 – Summary of the critical speed of the shared bogie cases.

The main conclusion is that the fact that vehicles are articulated positively affects the critical speed, while the mandatory reduction of the load in the first wheel sets affects negatively the speed when the vehicle gets unstable. The total expected reduction in the top speed is lower than 20% for laden vehicles and no reduction for empty vehicles, using the existing non-articulated Y25 vehicles as a maximum speed reference.

Conclusions: single wheel set vehicles

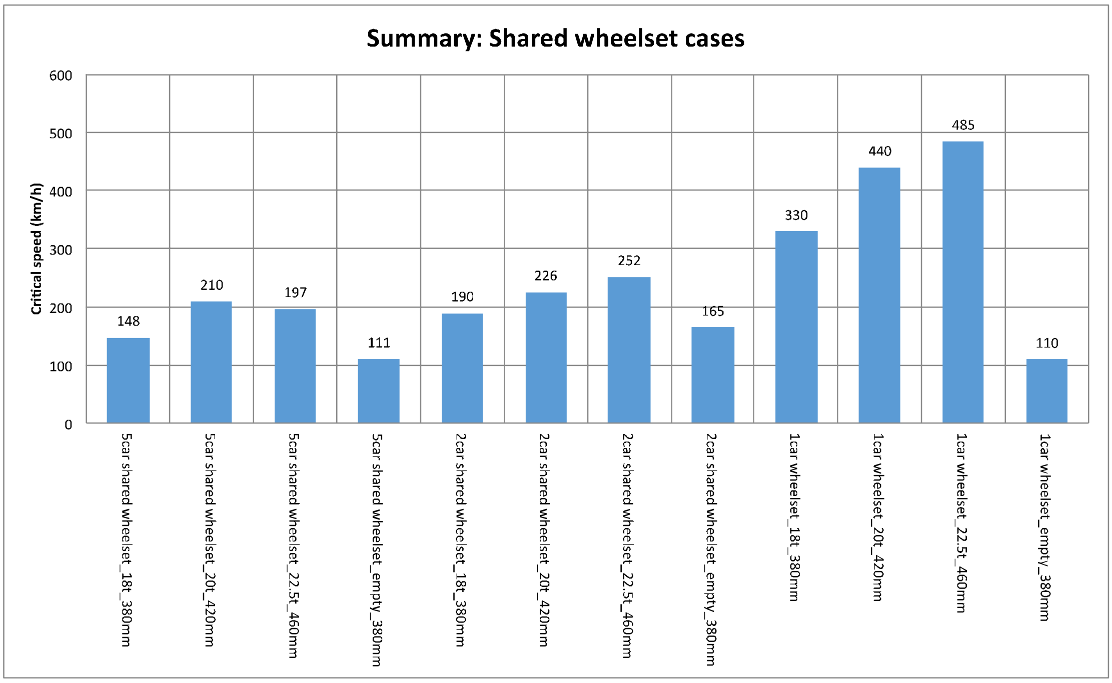


Figure 3 – Summary of the critical speed of the shared wheel set cases.

Single wheel set consists, in any configuration and any load case, have no theoretical issues with the critical speed of the vehicle. For a conservative friction value of 0.35, the most limiting speed is for 5 car articulated empty vehicles, which is the same as for the short-coupled reference, meaning that there is no theoretical decrease in the critical speed when using several vehicles coupled in a single consist. For the laden case, critical speed increases with axle load and wheel diameter, and is higher than 148 km/h for any case. The critical speed is not the limiting factor for single wheel set configurations.

1.2. Curving Ability:

The curving simulation of the single car was first performed for the case of a small radius of 250m for a single car. But, due to the particularities of the articulated model, simulations with a radius of 250m could not be carried out. Due to the limitations in calendar time, simulations have subsequently been performed for a radius of 500m only. This does not mean that the 5 car models cannot run in real life in low radius curves, it is just the mathematical model that could not converge for the applied conditions.

The designed track is of 2 kms with track irregularities in it. The transition curve is 120m long over the course of which the radius decreases and the cant increases linearly.

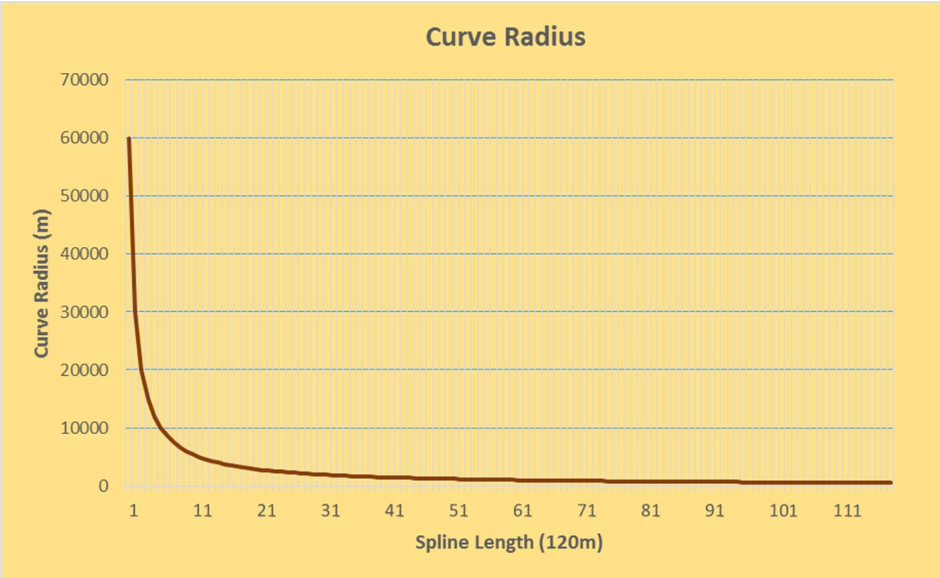


Figure4 – curve radius characteristics.

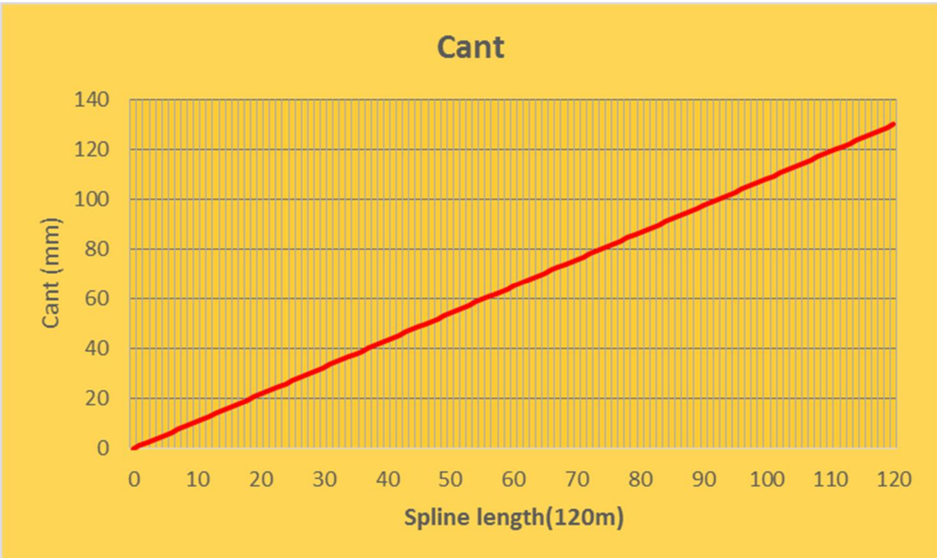
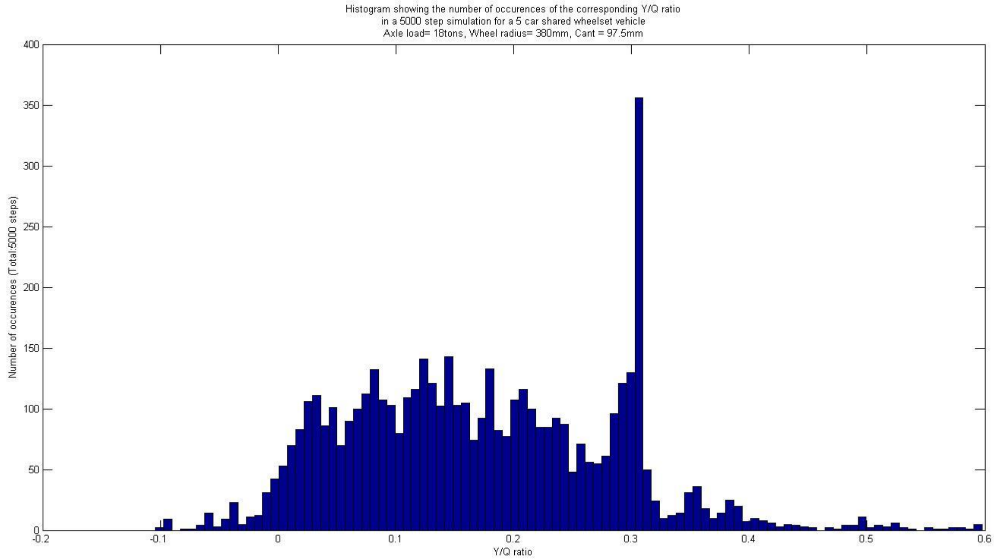


Figure5 – Curve cant characteristics.

For the given curve radius (500m) and cant (130 mm), the equilibrium speed is calculated as 75.86 km/h. This speed was used in the he equilibrium condition, cant excess and cant deficiency conditions by modifying the cant in the last two conditions.

The curving simulations yielded a value of Y/Q lower than 0.8 in all the cases hence proving it stable during curving.

A histogram for one of the cases is described in the figure:



2.1.3 Dynamic analysis: longitudinal dynamics

Longitudinal dynamics refers to the longitudinal forces transferred through the buffers of inter-wagon couplings.

The idea in this task is to assume that brake application is ideal, so the timing for the different braking solutions is a known variable. Then, with a one dimensional model of the train we can calculate the longitudinal force transfer between different wagons. Also, the influence of buffer distance for low radius curves.

2.1.3.1 Vehicle configurations

In order to study the influence of braking technologies on longitudinal force transfer, different vehicles are considered: VEL-wagon, articulated bogie vehicles and articulated single axle vehicles. Full trains with the different wagons will have different number of wagons and axles, and a different distance between couplers, which will enable a comparison between different business needs.

- VEL-wagon: VEL wagons are a novel concept based on the EU project "Versatile, Efficient and Longer Wagon for European Transportation" (December 2010 to December 2012). It is highly modular and can accommodate ISO containers up to a length of 80'.
- Shared bogie container transport vehicles
- Single axle car transport vehicles

2.1.3.2 Brake control modes

The main objective of this task is to allow a fair comparison between different braking control technologies in order to decide if the technical advantages of using novel and/or more expensive brake control systems is cost efficient. The technologies to be investigated are classic pneumatic (P) control, pneumatic control with End of Train device (EoT) and electro-pneumatic (EP) braking.

P brakes

In this first case the braking signal is transferred via the pneumatic circuit. When the brake valve is released, compressed air from the signal pipe is evacuated, and when the pipe is empty at the position of the wheel set, the brake actuation starts. This means that the signal travels through the pipe at the speed that of the air evacuating the pipe, so the brakes will start functioning in a progressive pattern.

There is not one single configuration for the pneumatic braking. There are UIC provisions, but also national provisions which may deviate from the initial ones. UIC 421 provisions are as follows:

- P (= loco and all wagons in P) up to a hauled mass of 800t
- G/P (= loco in G, all wagons in P) between 800t and 1.200t
- LL (="Long Locomotive", i.e. loco plus first five wagons in G, remaining wagons in P) between 1.200t and und 1.600t.
- G (=loco and all wagons in G) between 1.600 t and 2.500t (= maximum admissible hauled mass), vmax = 100 kph
- Other configurations are possible if a safety assessment is carried out. This applies, for instance, to centre buffer couplers [UIC 421]
- German DB Ril 402 provisions are as follows:
- P up to a hauled mass of 1.600t; 2.500t if all wagons > 32t and up 4.000t if all wagons > 40t

P is generally allowed if stabilized center-buffer couplers according to UIC are used.

Due to the different pneumatic brake configurations that can be found in the trains, in the following work P will be studied, where all the brake cylinders have the same force characteristic. Timing data for the simulations will come from Knorr-Bremse's simulations.

P brakes with EoT device

When looking for cost efficient solutions for novel braking systems, one of the most promising ones is the use of an End of Train device, a radio operated valve that releases the air from the end of the pipe when the brake is applied. Thus, the end of the train and the front start braking at the same time, and the delay caused by the speed of the air evacuating the pipe is then mitigated. Also, the total delay until all brakes are activated is halved.

In this case, the timing data will also come directly from Knorr-Bremse's simulations.

EP brakes

In this case, the braking signal is provided by an electronic system, ensuring that all wheel sets get the braking signal almost simultaneously. The downside is that the wagons would need couplers that include electric connections, which makes it a costly solution. This cost is reduced in cases where long wagons are used and connected by drawbars.

From a practical point of view, it is considered that all the brakes act at the same time. In this case, there is no transfer of longitudinal force between cars, as all cars have the same force at the same time. Thus, this case will not be simulated.

2.1.3.3 Technical data

Individual brake application

Each brake cylinder has a load curve, as it is not instantly applying the maximum force. This is dependent on the braking mode of the wagon.

- Load curve (F(t)) for the block brakes: (limits are acc. to UIC 540, TSI WAG also refers to this)
    - Slow G-Mode: If released brake is getting applied:
        - Quick built-up of ca. 10% of the max. brake cylinder force within few seconds ("inshot function").
        - Slower remaining force build-up within 18-30 sec until 95% of max. force.
    - Normal P-Mode: steady built-up time, at emergency braking within 3-5 sec (6 sec if load braking) between start and 95% of max. force reached – KE distributor valves xx sec
- Releasing Load curve (F(t)) for the block brakes:
    - Slow G-Mode: within 45-60 sec from start to falling below 0.4 bar cylinder pressure
    - Normal P-Mode: within 15-20 sec from start to falling below 0.4 bar cylinder pressure, within 15-25 sec for freight cars > 70t

The real values of brake application and releasing times scatter quite widely within the above limits. Even for the Knorr KE distributor valve there are different variants, and above all, the times are temperature dependent. As a conservative assumption, KB suggests to use 21s application time in G mode and 3.5s in P mode. These values correspond to the lower limits of the somewhat narrower EN 15355.

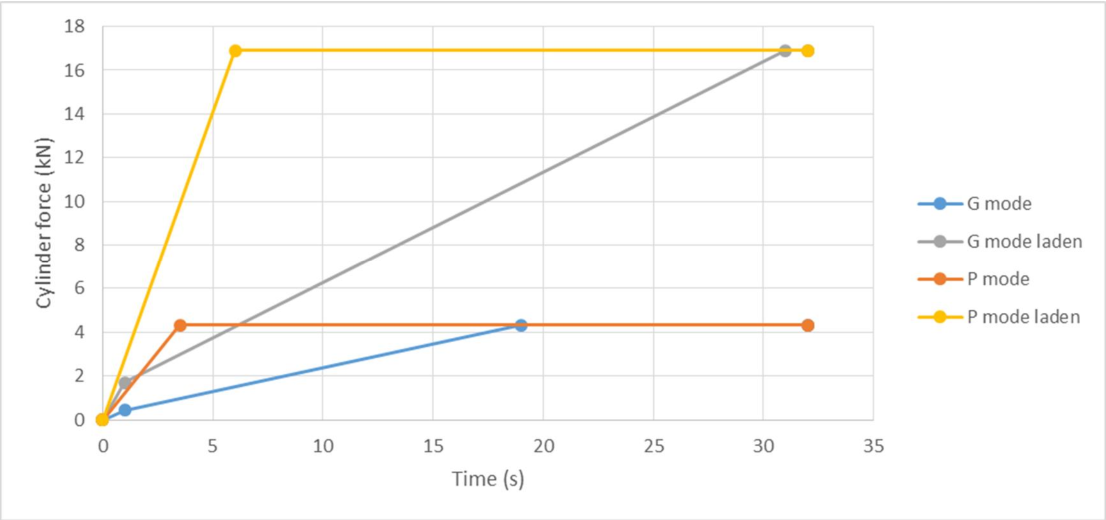


Figure 6 – loading characteristics according to the data provided by KB.

2.1.3.4 Modelling and simulation

The calculation is performed with one-dimensional models in Gensys. The model includes all the vehicles in the consists with their individual characteristics, the force-displacement and force-speed characteristics of the connections between car bodies, and the force and timing of the brake applications in each vehicle according to the simulations from Knorr Bremse.

Figure 7 – example of a model with a locomotive and several wagons.

2.1.3.5 Results and discussion

The results on this topic are still preliminary, so they are not included in this report.

2.2 Perspective on wheel damage due to block brakes

Block braking dissipates kinetic energy in the form of heat, which is partly transferred to the wheels and dissipated by them. This has major maintenance problems as temperatures above 500°C maintained for a certain period of time can cause different damage modes to appear, e.g. tread shelling.

The selected brake system, EP brake with brake blocks, has advantages regarding the time block brakes are acting on the wheels of the front part of the train, so the total heat transfer to these wheels will be reduced. Also, a reduced wheel diameter for an improved vertical gauge causes that the cumulated thermal energy is increased, so this innovation will probably decrease the life of the wheel sets.

Braking mechanics, thermal energy transfer and dissipation, thermal damage, and brake tribology are complex phenomena with complex interactions that need deep research in order to be fully comprehended. The time availability in C4R only allows for minor efforts towards the theoretical study of the benefits on maintenance when the braking control system is changed; this problem definitely needs further and deeper investigation in order to be able to obtain sound conclusions applicable in daily train design and operation.

The main objective of this section is to give an insight to the gains that could be achieved by using P-EoT or EP braking instead of P braking in tread-braked vehicles. The process is as follows

- Literature review: gather all the information there is about wheel damage related to thread braking. Separate it by topics:
    - Temperature build-up in the wheels
    - Damage in the wheels
        - Material softening (reduced young modulus)
        - Wear transitions
        - Hot spots
        - Crack development
    - Relate the two previous points: damage as a function of temperature (and ultimately braking)
- Braking time calculation for the proposed configurations, and extrapolation of the results in the previous literature review to the C4R case.

2.2.1 Temperature development due to braking

According to [4] the brake temperatures have a specific trend as in this figure:

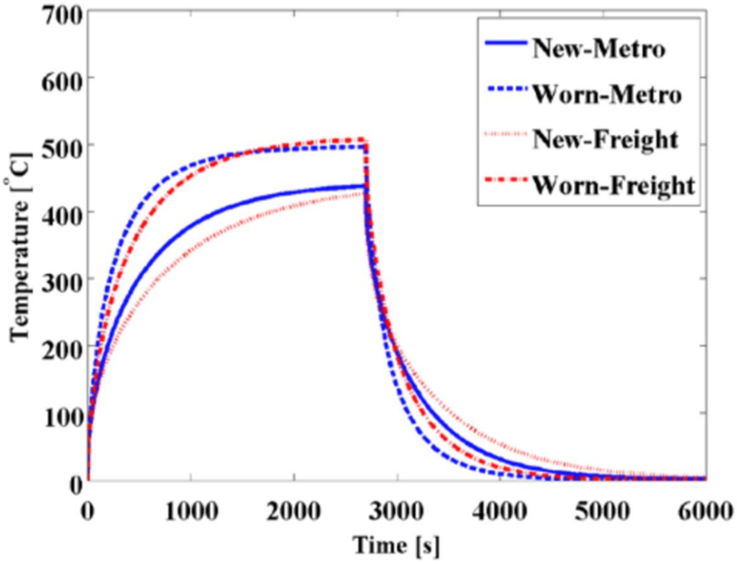


Figure 8 –Calculated maximum temperature on the tread for **drag braking** with rail chill.[4]

This means that the brake is sustained for a very long time, while maintaining the speed constant. If we stick to the first ca. 60s of this figure, that would be the temperature increase in a regular brake to stop, ca. 150°C.

2.2.2 Damage due to thermal effects

In [5] the crack increase due to thermal loading is analyzed.

"The results imply that fully functional brake systems are not likely to induce thermal crack propagation under normal stop braking, but that with pre-existing defects, a severe drag braking due to malfunctioning brakes may cause very deep cracking. These are "wheel braking cracks" which would completely destroy the wheel, so it is a safety issue and not a maintenance-related one.

In other paper [6] the relationship between the temperature and the wear regime transitions are studied. "Wear transitions occurring during running-in are decisive for the outcome of the rest of the test run."

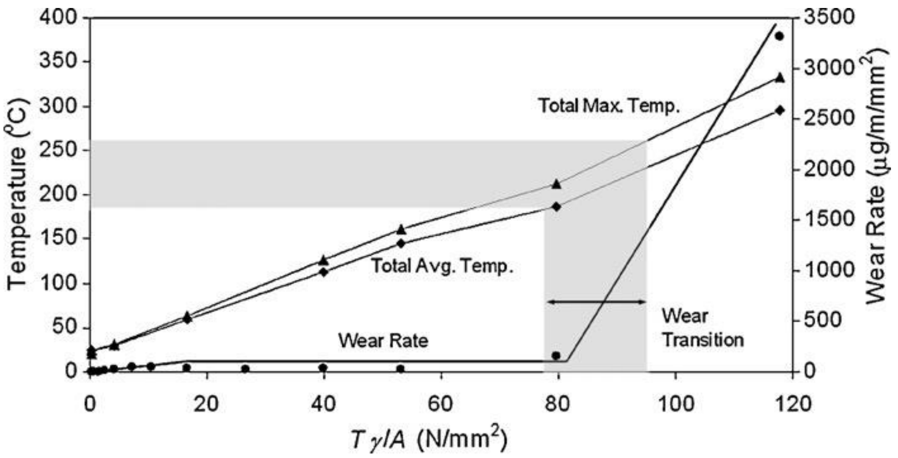


Figure 9 – wear transition dependence with temperature [6]

The figure shows that wear transition happens after ca. 200°C: "The British Steel Makers Creep Committee demonstrated that carbon manganese steels, similar to rail steels, experience thermal softening at approximately 200–300 °C, causing a drop in the yield strength." [*British Steel Makers Creep Committee, BSCC High Temperature Data, the Iron and Steel Institute for the BSCC, London, 1973*] Also, "Widiyarta et al. have modelled the thermal effects in ratcheting wear. It was found that the temperature rise at the contact surface will lead to an increased rate of damage accumulation by ratcheting causing a significantly increased wear rate and propensity for crack propagation."

Anyway, temperature seems to have different effects:

- Thermal softening, which will increase wear rates.
- Microstructural surface changes
    - To finer grain structures, which will decrease wear rates.
    - To austenitic structures that generate catastrophic wear.

Another reference [7] studied wear of block materials, but not wheels, concluding that around 550°C for cast iron and 500°C for organic there is a wear transition. There is no apparent wear transition for sinter block brake materials. This is only blocks and not wheels. There should also be taken into account the differences in thermal conductivity for novel materials, which will reduce the heat conduction through them and thus increase wheel temperature.

For cast iron there is an increase and then decrease, due to the initial generation of an oxide layer which is brittle compared to the metal, and then is hardened again when the oxidation layer is increased enough to be resistant again.

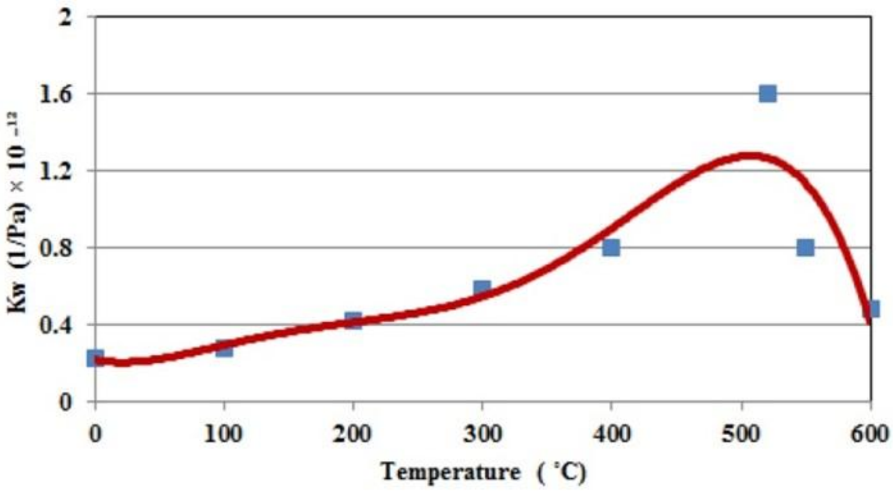


Figure 10 – wear coefficient dependence on temperature[8]

Here they study the influence of temp on ratcheting damage [9]. As it can be seen in the next figure, the normalized yield stress is minimal between 400°C and 500°C.

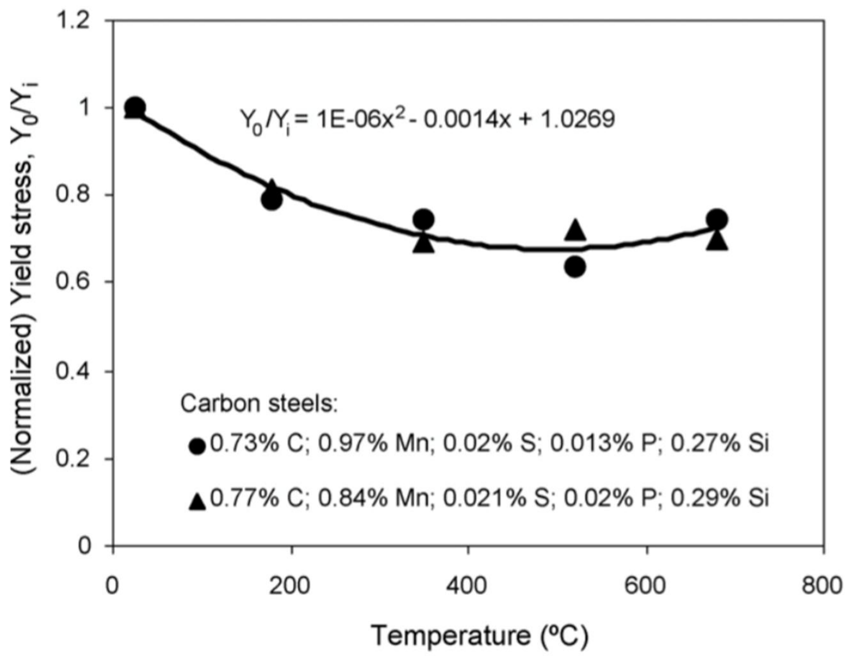


Figure 11 – yield stress dependence on temperature[9]

In this article, wheel-rail rolling generated contact is analyzed. There, it is stated that, for a single wheel pass and normal running conditions, the temperature in the wheel is not enough for phase transformation at min 600°C [10], but it is enough for a weakening of the material (yield stress reduction of up to 40%). With a slip-roll ratio of -5%, the subsurface temperature is plotted in the next figure.

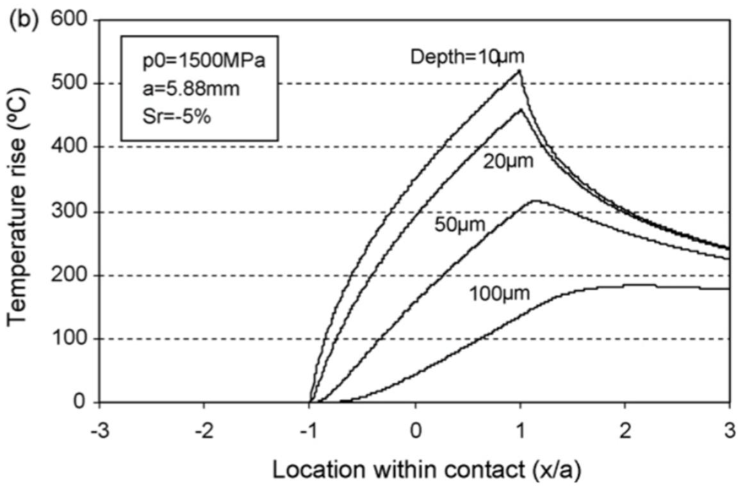
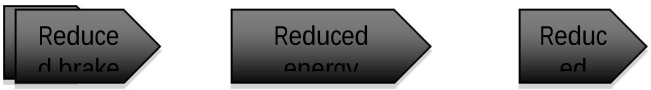


Figure 12 – sub-surface temperature rise in the wheel-rail contact[10]

Eventually, material softening favors ratcheting accumulation, speeding up material failure. There is also an increased wear rate and the material has a propensity for crack initiation.

2.3 Benefits of EP braking regarding thermal damage

After this review, the question remains if introducing EP brakes will reduce wheel damage. The reasoning is depicted in Figure 123.



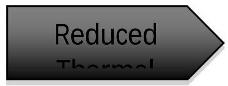


Figure 13– damage reduction due to EP braking

Now, as the time for this calculations is rather limited, the work has been performed in the following way:

1. From KB calculations, the time delay between P braking and EP braking is obtained. Alternatively, the energy dissipated in each wheel can be obtained.
2. From these results and according to scientific literature, a temperature at the wheel tread is estimated.
3. With the estimated temperature, the thermal damage types that are most likely to occur on the wheel will be discussed, specially the possible reduction of the different types of damage.

The study is carried out for articulated 6-axle container consists with Y25 running gear, carrying K-blocks and load braking limit 16t/axle and the following conditions:

a) 750m trains with conventional pneumatic brake
b) 750m trains with EP brake
c) 1100m trains with conventional pneumatic brake

d) 1100m trains with radio End-of-Train device (EOT)
e) 1100m trains with EP brake

The qualitative results are applicable to any vehicle that changes from P to EP brakes.

Brake time

Configuration	t(s)
a) 750m trains with conventional pneumatic brake	46,4
b) 750m trains with EP brake	37,7
c) 1100m trains with conventional pneumatic brake	52,1
d) 1100m trains with radio End-of-Train device (EOT)	41,5
e) 1100m trains with EP brake	37,8

The biggest difference in brake time is ca. 15s between cases e) and c).

Brake temperature

As it has been seen before, the temperature increase in 60s is ca. 150°C. Assuming a linear increase, the temperature will be reduced from 130°C (c) to 100°C (e).

Wheel damage

As it has been seen in the literature review, thermal damage appears in the following thresholds:

- Material softening: around 5% between 130°C and 100°C (as in the current worst-case scenario)
- Wear ratio: 200-300°C to 500-550°C depending on the publication
- Hot-spots: >500°C
- Increased crack propagation: during regular rolling contact, ratcheting is favored due to thermal effects. Not studied for braking contact.

3 Conclusions and further work

There are straightforward benefits on using EP brakes for vehicle safety, brake time, brake length, etc. However, the benefits on reducing wheel damage when using block brakes are not so obvious, for regular brake to stop, or for emergency braking, where the temperature increase will not justify a substantial improvement in the damage sustained by the wheel threads.

According to some references, for sustained braking at constant speed there can be a temperature of 500°C at the tread is reached after 2000s of brake application. In this case, two practical approaches are employed: i) constant braking or ii) strong braking periods combined with no braking periods. Apparently the second case deals less damage on the wheels. Considering also the lack of empirical data on novel brake block materials, this should definitely be studied more, e.g. in Shift2Rail.

4 Defining the main KPIs to assess the progress of efficiency

a. Reminder of the demands of the shippers, forwarders, operators

The main demands are related to reliability and cost reduction. To achieve these objectives we have to define which are the main parameters impacting these main targets.

i. Reliability is mainly impacted by the technical reliability of the rolling stock and in our case by the reliability of the wagons implying a high level of quality of the maintenance. This may be achieved by the introduction of predictive maintenance.

ii. Reliability is also extremely dependent on the train management. In this field the question of a full respect of the departure time from the terminal is fundamental. This may be obtained by a very strict organization of the operations on the terminal which is helped by an efficient preparation of the operations. A precise ETA (Estimated Time of Arrival) at the terminal is extremely efficient and for that reason installation of autonomous track and trace devices on the train and the wagons is important with a real transfer of the position information to the interested parties.

iii. Reliability being dependent on the path quality and on the priority given to the train it has been frequently suggested to increase the freight train speed. But the loss of capacity of transport at a higher speed for safety reasons reserves that solution to very high value products which transport can afford such a reduction of payload in a train. Between 100km/h and 200Km/h the payload is in average reduced from 1200T to 110T.The decrease is near linear in the range from 100km/h to 120km/H , a little more important proportionally until 140km/h and then it is no longer linear and the payload drops to 110T at 200km/h. The other solution, besides getting a dedicated freight network or a higher freight priority, is to enhance the maneuverability of the freight trains which may be obtained with synchronous braking and releasing with quick reactions. EP brake solution proposed in the present project has that goal.

iv. Cost reduction is the result of progress on several parameters:

1. The increase of the usable length enables to reduce the transport cost per meter which may be interesting for light cargo with large volumes.
2. The payload increase reduces also the transport cost per ton
3. The improved flexibility of the type of units which can be loaded improves the asset utilization
4. The better reliability of the equipment improves the overall available time for transport and reduces asset cost per trip.
5. An improved path is equivalent to an average reduction of the transit time and thus reduces the cost of the asset per trip.
6. An improved path reducing the transit time impacts the major cost factor : driver cost,

b. What KPIs can represent the progress of efficiency in these fields

i. The normal statistical assessment of the reliability is the ratio between the numbers of effective fulfillments of the contract divided by the number of application of the contract. This KPI is the result of the efforts made on the various parameters. Some indicators would characterize easily the increased quality of the maintenance: number of incidents for each category of equipment (Rolling stock) divided by the number of kilometers performed.

ii. For the path quality, which is essential to achieve a better reliability it is necessary to appreciate its resilience to incidents.. For that purpose a regular survey of the incidents happening during the trip generating a certain amount of lost minutes at the point of the incident must be put in correlation with the number of minutes lost at the arrival of the trip. The following KPI: (1-(number of minutes lost at arrival/number of minutes lost at the point of the incident or incidents)*100%) will represent the capacity of the path and of the train management to recover the difficulties encountered or even a late departure.

iii. For the cost reduction which is the global result of several impacts the possible KPIs are quite classical:

1. The percentage of usable length to place cargo
2. The ratio between the payload and the gross weight of the train measured in percentage
3. The average number of loaded kilometers per year of the wagons
4. The average number of empty kilometers per year of the wagons
5. The average commercial speed of the train divided by the maximum speed allowed of the train
6. The cost of wagon maintenance per kilometer and the cost of maintenance per ton-km transported

All these KPIs would indicate if the results of the innovations enable to progress towards the targets set up by the users and /or their clients.

c. Expected impacts of the various measures and innovations proposed in the project

i. Without extremely complex simulations on the impact of each innovation on a given traffic on the Rail Network, which are largely beyond the scope of the present project because of the limited resources, the expected impacts will be established on the basis of operational expert’s advice.

ii. However for certain KPIs the physical impacts maybe easily assessed:

1. For the 12 axel wagon carrying swap-bodies the reduction of length is 1,8% which leads to an increase of a carrying capacity of 2 more swap-bodies per train (50 instead of 48)
2. For the 6 axel and 5 bodies for automotive traffics the impact in term of capacity is depending on the size of finished cars that are to be transported and on the type of present utilized wagons:

Car segments	5 bodies / 6 axles 64,78m x 8 = 518m	2 bodies / 4 axles 30,66m x 17 = 521m	2 bodies / 3 axles 26,50m x 20 = 530m	difference
< 3,55m	272 cars	238 cars	260 cars	+12%>d> +4,6%
< 3,78m	256 cars	238 cars	240 cars	+16%>d> +6,6%

< 4,05m	240 cars	238 cars	240 cars	=
< 4,35m	224 cars	204 cars	200 cars	+20%>d> +9,8%
< 4,69m	208 cars	204 cars	200 cars	+4%>d> +2%
< 5,10m	192 cars	170 cars	180 cars	+12%>d> +6,6%

Because the precise calculation of the resistance of the wagons in the new optimized design cannot be done within the scope of this project, it seems preferable to reduce a little the length of each body of the New 6 axel- 5 bodies wagon as the reference of the structure are already existing. The impact is a little loss of 2 cars in term of capacity but it gives a side advantage in allowing to reduce the number of Chocks necessary which implies an operating cost reduction. The results are in the following table.

Wagons -> Train set -> Car segments	8(5 bodies / 6 axles) +1 (twin bodies / 3 axels) 8 x 61,8 + 28,2 = 522m	2 bodies / 4 axles 30,66m x 17 = 521m	2 bodies / 3 axles 26,50m x 20 = 530m	difference
< 3,55m	cars 270	272 cars- 4 chocks	240 cars	-2
< 3,78m	cars 252	238 cars	240 cars	+12 +5%
< 4,05m	cars 236	238 cars- 4 chocks	240 cars- 4chocks	- 4
< 4,35m	cars 218	204 cars	200 cars	+14 + 7%
< 4,69m	cars 202	204 cars	200 cars	-2
< 5,10m	cars 186	170 cars	160 cars	+16 +9,3%

3. For a 12 axel wagon carrying 5 swap bodies or 45' containers the impact in term of capacity results from the comparison with the most efficient existing wagons SGGMRSS 90' . The improvement is 4,1% and results in an extra 2 swap bodies more on the train.
4. For the 12 axel wagon carrying crane-able semitrailers the impact in term of capacity is to be compared to the most efficient wagons available on the market. The assumption is to compare the best solution existing today on the market to transport 4m height crane-able semitrailers of 27T on pocket wagons and our proposed solution within the maximum length of train authorized: 750m including the Locomotive.

	Number of wagons	Total length of wagons	UNITS	DEAD WEIGHT	Payload	Total Weight
New Proposed solution	10 x 4 w + 1 X 2W + 1 W = 43W	725M	43	10X67,65+34+17, 3=727,8 T	43X27= 1161 T	1888,8 T
T3000 solution	21 X T3000	714m	42	720 T	1134 T	1854 T

This table shows a gain of one semitrailer in length (2.4%) while remaining within the traction capacity of classical powerful electric or diesel locomotive.

5 Cost Benefit analysis

d. Expert assessment of the impact of the electric line and of the EP brake

i. The improvement on the maneuverability of the car transportation train could allow a gain of 20% on the average commercial speed as those trains would have the capacity to avoid certain stops when there is no possibility to insert a path in between two passenger regional trains in a situation where the freight train would have been obliged to stop involving a significant time to restart. The impact on the asset rotation would be lower as it involves the unloading, loading and preparation of the train for departure from terminals. It could be reduced to 10% according to the distance between terminals. Of course any other operation of marshalling or reshuffling of the train would reduce the impact. However the electric line and EP brakes allow to reduce the preparation time and/or the number of staff deployed for that purpose. This would enable to reach a target of 15% of improvement in asset rotation.

ii. The introduction of the electric line carrying a bus of information enables to install devices allowing the introduction of predictive maintenance. It can be estimated an improvement of the availability of 5% to 10% according to the present maintenance methodology: standard time between technical stops or stops connected to the effective work performed.

iii. The introduction of the electric line may allow to carry on the nearest wagons from the locomotive some reefer containers without installing specific energy production device on the wagons. This market requests a high level of reliability of the availability of the energy as perishables are demanding a very precise temperature control. For frozen food the flexibility may be greater in term of temperature range authorized between -30°C and -20°C giving time to realign the temperature at its maximum.

e. Global impact of the capacity improvement and the indications of the experts on the improvements linked to other factors

i. For the car transportation business:
The capacity improvement of each train composed of these new 6-axel/5 bodies wagon can be estimated in average (for various type of cars) at 10%.
The asset rotation would increase by 15% if we take into account a new preparation method and the predictive maintenance an increase of the availability of around 5%. This would globally result in 30% increase capacity.

ii. For the Container transportation business:
The capacity improvement is 2 more swap bodies on 48 which means around 4% increase. The

system would also benefit also of the 15% improvement of asset rotation linked to the new preparation method and to the predictive maintenance. This would result globally in capacity increase of around 20%.

iii. For the 12 axel/4 crane-able semi-trailer wagons incorporated in the trains, the capacity increase would be 2.4%. This system would also benefit from the other improvements quoted here above leading to a global gain of capacity of 17.4%.

iv. All these benefits should be partly reduced because of the consequences of any unexpected break down implying a complex withdrawal of a part of the multi-axel wagon. Despite an introduction of predictive maintenance some breakdowns may happen. For that reason a 5% reduction on these increase seems reasonable on the basis of expert advice.

v. The other factor inviting to minimize slightly the expected benefits is the existing certain restrictive speed limits when certain parts of the train are empty in case of traffics imbalance. The impact should be minimal as the cases where these constraints would appear are not very frequent.

f. Cost evaluation

i. For this analysis the manufacturer has assumed that the quotation should be based on the industrial cost of such wagons for large series. This is essential to make a comparison with the existing wagons quoted in this analysis.

ii. The basis of the comparison have been defined by NTnetAB in the following table :

	Standard solution	Cost for the standard wagon	New solution	Cost for the new multi axel wagon
Car transportation	2 bodies/3axel wagon:25,60m	113000€	5 bodies/6 axel wagon:61,8m	267000€
Containers transportation	SGGMRSS 90': 29,59m	67500€	5 bodies/12 axel wagon:71,930m	145000€
Crane-able Semi trailer transportation	6 axel pocket wagon:34,2m	117000€	4 bodies/12axel wagon: 67,28m	224000€

On these basis the cost of the various type of trains may be calculated within the length limits previously calculated in order to comply also with the axel loads limits. This will represent the asset costs to which will be applied the gains of efficiency calculated before for each category of traffic.

To fully implement the efficiency increase the equipment of the wagons with EP braking with an overlay solution could be useful on the new designed wagons. The example of the US trains gives an indicative cost of around 6000€ per wagon body and 15000€ per train for the locomotive (after sharing the cost between 3 sets of wagons) to install the EP braking solution.

iii. Train cost calculation
Applying the basis presented here above the cost of the various train at their optimum capacity is in the following table:

Type of traffic	Standard solution	New design solution	EP brake impact	Total cost of new design solution	Cost variation	Expected efficiency increase
Car transportation	28 W =3,164M €	11Wnew+1Std =3,050M€	0,267M €	3,317M€	4,8%	30%
Containers transportation	24W = 1,632M€	10WN = 1,45M€	without	1,45M€	-12%	4,1%
Crane-able Semi trailer transportation	21W= 2457K€	10WN +1W+1/2 W= 2437K€	without	2437K€	-1%	2,4%

g. CONCLUSION

i. The various proposals of new wagon designs are very interesting for the car transportation wagons where the benefits appear very significant for certain categories of car lengths.
   It is possible to reach around 25% gain in the transportation costs because of the asset rotation, the direct gain in capacity in a given length and a reduction of maintenance. The reduction of the number of axels as long as the stability of the wagon is correct and as long as the speed limit does not appear to be penalizing, induces naturally a reduction of the maintenance cost beyond the simple reduction linked to the possible predictive maintenance.
ii. For the container transportation wagons the cost reduction should reach 16% even without introducing a better train maneuverability. However the gain on the maintenance resulting from the reduction of the number of axels per container carried (2.4 axel/container versus 3/container) should even reduce more the transportation cost.
iii. For the container transportation the proposed solution to have the possibility of a partial flexibility to carry 20´, 40’, 45’ containers applied to 60’ wagons is applicable for 30% of the containers to be 45’ without an increase of the train length but with a constraint of working by blocks of 3 wagons not able to be uncoupled operationally because of the absence of the free rectangle of Bern necessary for the staff safety when decoupling. The increase in capacity in terms of units is limited to 7%. But it is also applicable for 80’ wagons on which you can place 2 x 45’ containers every group of 3 x 80’ wagons not to be uncoupled operationally. On trains of 720m (without the locomotive) you could transport 54 units of which 18 could be 45’ units instead of 48 units of which 48 could be 45’ units. The gain of efficiency is 12.5%.
iv. For the crane-able semi-trailer transportation trains the new wagon design creates a little efficiency of 3.4% which would not be sufficient for a positive wagon owner decision of investment.
v. For all types of transport, specifically if uncoupling wagons is not frequent, for instance for shuttle trains, the reduction of time of preparation of the train before departure is a very positive progress. For that purpose equipping the train with an electric line and with an End of Train device enables to perform a brake test from the driver’s cabin if sensors have been installed on the wagons. This could be a first step of progress before installing an EP braking system.

6 References

[1] I. Persson, “GENSYS.1312 Reference Manual,” DEsolver AB, 2013.

[2] H. Molatefi, M. Hecht, and M. H. Kadivar, “Critical speed and limit cycles in the empty Y25-freight wagon,” *Proc. Inst. Mech. Eng. Part F J. Rail Rapid Transit*, vol. 220, no. 4, pp. 347–359, Jul. 2006.

[3] S. Iwnicki, Y. Bezin, A. Orlova, P.-A. Jönsson, S. Stichel, and H. Schelle, “The ‘SUSTRAIL’ High Speed Freight Vehicle : Simulation of Novel Running Gear Design,” presented at the 23rd International Symposium on Dynamics of Vehicles on Roads and on Tracks, Qingdao, China, 2013.

[4] T. V. ShahabTeimourimanesh, “Braking capacity of railway wheels – state-of-the-art survey,” presented at the 16th International Wheelset Congress (IWC16), Cape Town (RSA), 2010.

[5] S. Caprioli, T. Vernersson, and A. Ekberg, “Thermal cracking of a railway wheel tread due to tread braking–critical crack sizes and in fluence of repeated thermal cycles,” *Proc. Inst. Mech. Eng. Part F J. Rail Rapid Transit*, vol. 227, no. 1, pp. 10–18, Jan. 2013.

[6] J. Sundh and U. Olofsson, “Relating contact temperature and wear transitions in a wheel–rail contact,” *Wear*, vol. 271, no. 1–2, pp. 78–85, May 2011.

[7] T. Vernersson, R. Lunden, S. Abbasi, and U. Olofsson, “Wear of Railway brake block materials at elevated temperatures; pin-on-disc experiments,” presented at the TheEuroBrake conference, Dresden, Germany, 2012.

[8] S. Abbasi, S. Teimourimanesh, T. Vernersson, U. Sellgren, U. Olofsson, and R. Lundén, “Temperature and thermoelastic instability at tread braking using cast iron friction material,” *Wear*, vol. 314, no. 1–2, pp. 171–180, Jun. 2014.

[9] I. M. Widiyarta, F. J. Franklin, and A. Kapoor, “Modelling thermal effects in ratcheting-led wear and rolling contact fatigue,” *Wear*, vol. 265, no. 9–10, pp. 1325–1331, Oct. 2008.

[10] G. Baumann, H. J. Fecht, and S. Liebelt, “Formation of white-etching layers on rail treads,” *Wear*, vol. 191, no. 1–2, pp. 133–140, Jan. 1996.